SHASTA LAKE
WATER RESOURCES INVESTIGATION

APPENDIX C

Conjunctive Water Management Assessment

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CHAPTER I
INTRODUCTION

Conjunctive water management involves the coordinated use of groundwater and surface water to minimize the impacts of water shortages and increase water supply reliability. Conjunctive water management uses groundwater to meet demands in dry years when surface water supplies are limited, and surface water to meet demands in wet years when surface water supplies are not limited. Conjunctive water management is a viable method of increasing the efficiency of a system because it uses a wider range of resources, expanding the options available to meet system demands.

In physical terms, the Sacramento Valley is especially well suited for conjunctive water management, possessing both large surface water supplies and vast groundwater aquifers. However, in most regions of the Sacramento Valley, historical water development has concentrated on surface water, leaving groundwater relatively undeveloped, and conjunctive water management opportunities largely unexamined. The general blueprint for Sacramento Valley conjunctive water management involves extracting groundwater strategically to increase local supply or to enable reduced diversions of surface water at critical times, and allowing the groundwater aquifer to recharge, either through active recharge or natural recharge due to reduced pumping, during wet periods. Diversion reductions could make water available to other water users or for environmental purposes.

TYPES OF CONJUNCTIVE WATER MANAGEMENT

Conjunctive water management can involve two primary strategies: in-lieu and active recharge. Both in-lieu and active recharge operations can increase the functional storage available to the system.

In-Lieu Conjunctive Water Management

An in-lieu conjunctive water management program increases system flexibility and water supply reliability when participants use groundwater "in-lieu" of surface water deliveries during dry periods. In-lieu conjunctive water management increases groundwater pumping during dry periods, thus reducing surface water deliveries and freeing up surface water for other users. During wet years, surface water deliveries are increased, thus reducing groundwater pumping and allowing the groundwater aquifer to naturally recharge. As shown in **Figures I-1** and **I-2**, wet periods are identified as "put cycles" when groundwater pumping is reduced and the aquifer is naturally recharged, and dry periods are identified as "take cycles" when groundwater is extracted.

Operationally, both types of conjunctive water management are similar; when surface water is available, deliveries are increased compared to existing operations. For in-lieu operations, additional surface water deliveries are used to replace deliveries previously deriving from groundwater. In the context of an enlarged Shasta Dam, in-lieu conjunctive water management would make use of increased storage at times of ample water. By delivering to conjunctive water management participants water that would otherwise have been spilled and released to the ocean, the reservoir can be partially emptied and allowed to refill, thus increasing the efficiency

of the reservoir. During dry periods, when inflows into Shasta Reservoir and other surface water reservoirs are low, conjunctive use participants would meet their demands with groundwater rather than from surface water, freeing up surface water for export to other contractors. The net amount of surface water delivered during these dry periods may not change compared to the baseline, but the substituted groundwater deliveries would create greater surface water reliability throughout the system.

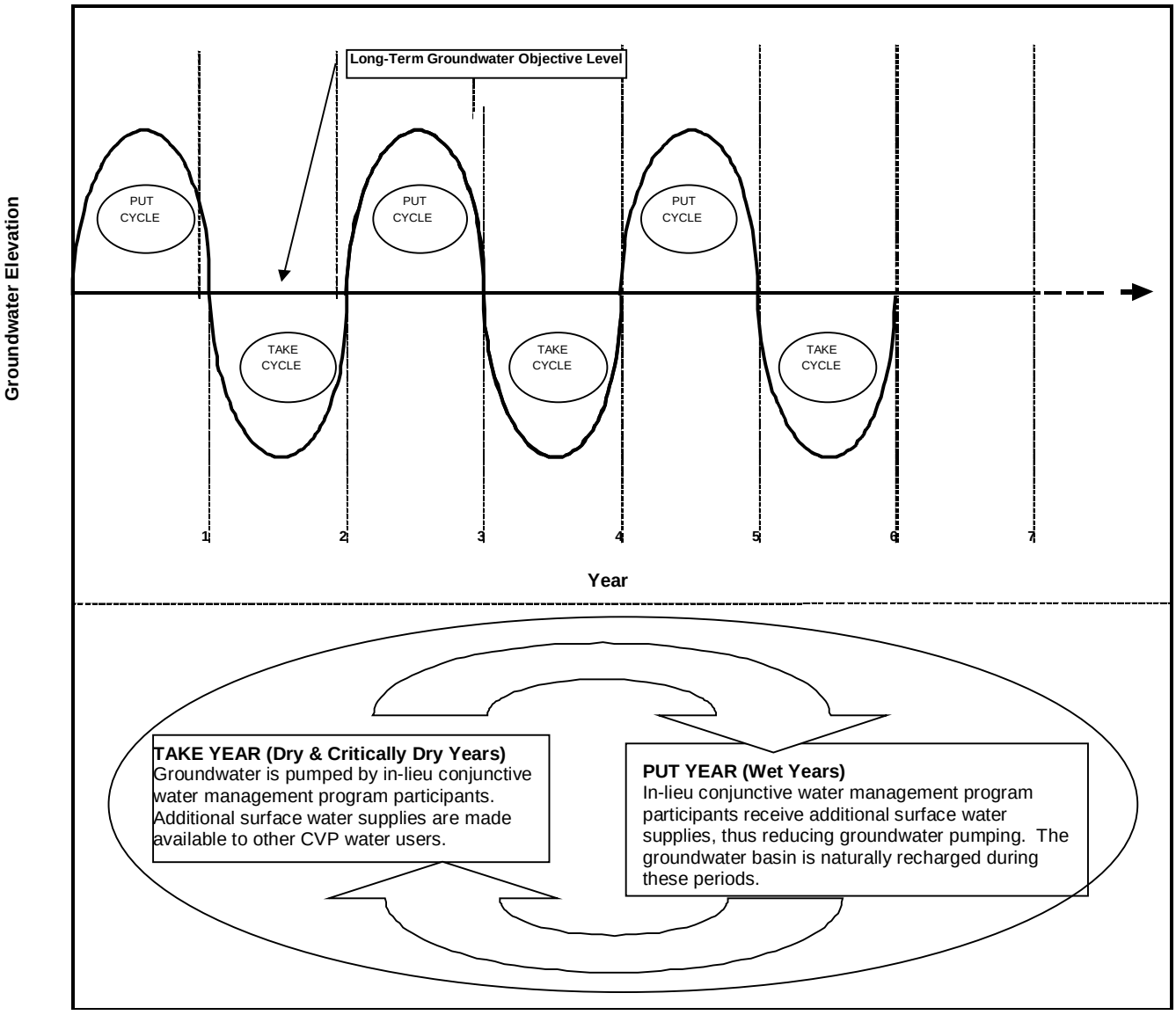

Figure I-1
In-lieu conjunctive water management cycle.

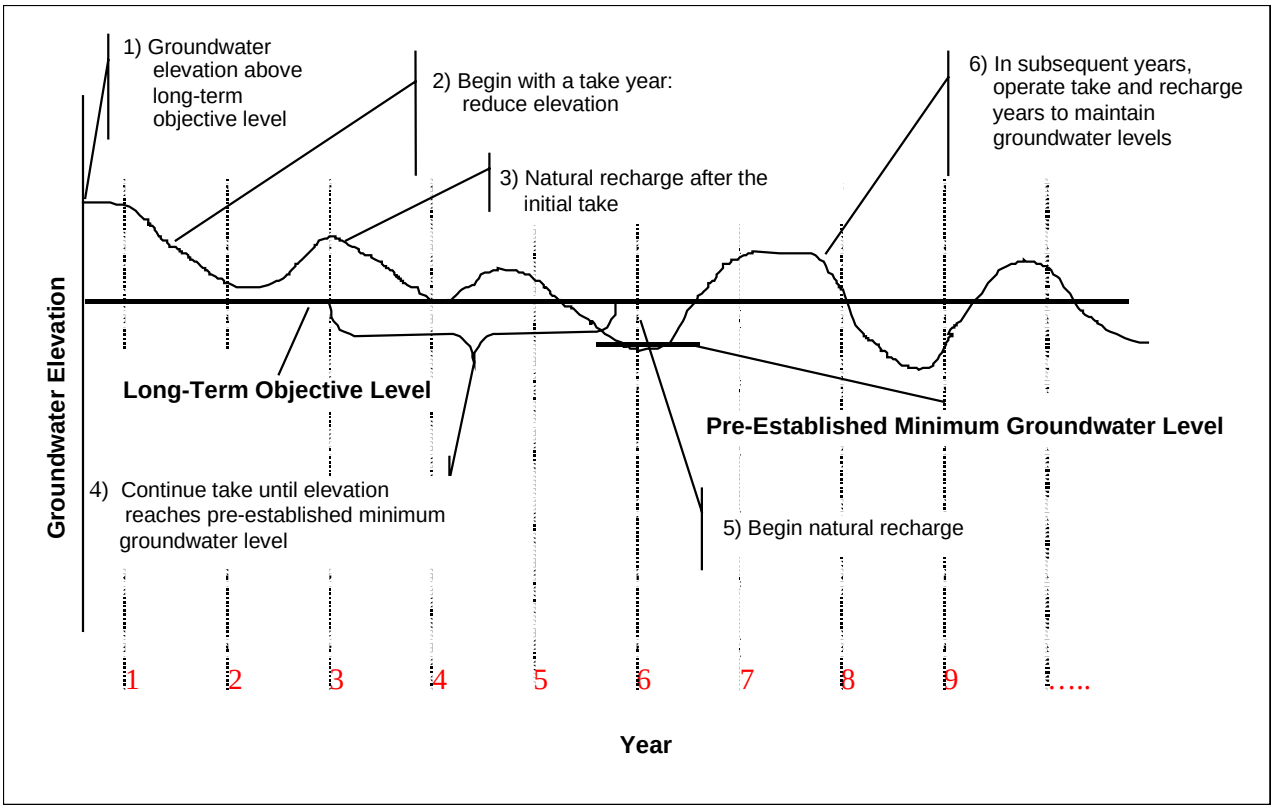

Figure I-2
Hypothetical conjunctive water management program beginning with a "take" year.

Active Recharge

For active recharge operations, groundwater resources are actively recharged with surface water through injection wells or recharge ponds. The goal of active recharge is increased groundwater storage due to a deliberate introduction of surface water to the groundwater aquifer. Active recharge is operationally equivalent to storing water in a surface reservoir, but the water is stored in a groundwater aquifer. Under active recharge operations, surface water deliveries are stored as groundwater for use at a later time.

An active recharge conjunctive water management program could be combined with an enlarged Shasta Dam. However for regions with high naturally recharge, such as the northern Sacramento Valley, active recharge is not as efficient as in-lieu recharge due to the additional capital and operations and maintenance (O&M) cost associated with active recharge facilities. Consequently, subsequent discussions primarily focus on in-lieu conjunctive water management opportunities related to an enlarged Shasta Dam and Reservoir.

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CHAPTER II
IN-LIEU CONJUNCTIVE WATER MANAGEMENT OPPORTUNITIES

Primary limitations in increasing system yield for an enlarged Shasta Reservoir are the timing of inflows and timing of the demand for water. Under existing conditions, demands are typically met during wet periods while shortages occur during dry periods. An enlarged Shasta Reservoir could capture more inflows during wet periods, but since the system demands are already largely met during these times, the water would be stored instead of being released. During these wet periods, transfer of stored water to the San Joaquin Valley would be limited by physical and institutional limitations on the Sacramento-San Joaquin River Delta (Delta) pumping. Hence, much of the benefit from an enlarged Shasta Reservoir is unusable during wet periods and the reservoir remains full, with any additional inflows spilled. However, historical hydrology suggests that if the reservoir were exercised, and the level were drawn down every year (including wet years), Shasta Reservoir would still fill in a majority of years.

To increase the efficiency of storage developed in Shasta Reservoir, a potential in-lieu conjunctive water management program was considered. The program would include Central Valley Project (CVP) contractors receiving additional surface water deliveries during wetter periods, resulting in reduced groundwater pumping during these periods. Through this reduction in groundwater pumping during wet periods, groundwater in the region would naturally recharge at a higher rate. During dryer years, when surface water deliveries were less than 100 percent of contract quantities from the CVP, participating contractors would meet a portion of unmet deliveries by pumping groundwater. This would create an additional demand for surface water in wet years, allowing Shasta Reservoir to be drawn down (creating an opportunity to refill), while allowing groundwater aquifers to recharge due to reduced pumping.

In exchange for increased surface water deliveries during wet periods, participating contractors' surface water deliveries would be reduced during drier periods and contractors would draw on groundwater to meet demand. During these periods, water that would otherwise have been delivered to contractors could be exported out of the Delta to other CVP contractors. In exchange for a reduction in dry year surface water deliveries, conjunctive water management program participants would receive average annual deliveries greater than they currently receive.

CVP CONTRACT TYPES

CVP contracts can be divided into three categories, listed below in order of priority:

1. **Settlement and Exchange Contracts -** These contracts are held by users with senior water rights that predate construction of the CVP. These supplies are guaranteed for all but the driest years.

2. **Municipal and Industrial Contracts (M&I) -** These contracts are for urban water usage and represent the smallest volume for deliveries of the three categories. These supplies are subject to reductions at a greater rate than settlement and exchange contracts.

3. **Agricultural Contracts (Ag) -** These contracts represent a relatively large portion of total deliveries and are subject to the highest amount of shortages. Ag contractors are always

subject to delivery reductions before deliveries are reduced to holders of the other two contract types.

Water is allocated throughout the system according to these contract types. Depending on available water and forecasted inflows, the total volume of deliveries is established. Unless the year is classified as "critical" according to the Shasta Index, Settlement and Exchange Contractors receive their full contract quantities. For M&I and Ag contractors, deliveries are subject to shortages. Agricultural contractor deliveries are reduced to 75 percent of contract quantities before M&I deliveries are reduced. If agricultural allocations fall below 75 percent of contract quantities, Ag and M&I deliveries are reduced at the same rate until M&I allocations are reduced to 75 percent and agricultural allocations are reduced to 50 percent of contract quantities. The next 25 percent increment is borne by Ag contractors; their deliveries are reduced to 25 percent of contract quantities. When the agricultural deliveries are reduced from 25 percent to 0 percent of contract quantities, M&I deliveries are reduced from 75 percent to 50 percent.

HISTORICAL CONTRACT ALLOCATIONS

During the past 15 years, the hydrology and operations of the CVP have been subject to both a prolonged drought and years of plentiful water supply. Historical allocations to the various CVP contract types for this period are shown in **Table II-1**. During this period, Ag north contractors could receive more water for several years; 1997 and 2001 were dry years with surface water reductions, but M&I and other higher priority contractors received a greater portion of their allocations. Similar future periods are believed to be ideal for a potential in-lieu conjunctive water management program. Allocations for all contractors were also greatly reduced in 1991, 1992, and 1993, when all contractors received a very small portion of their demand. During such periods, surface water normally delivered to Ag north contractors could be replaced with groundwater, and surface water could be redistributed throughout the system to increase the reliability of the other contractors.

TABLE II-1
SUMMARY OF HISTORICAL ANNUAL CVP WATER SUPPLY ALLOCATION PERCENTAGES SINCE 1990 [1]

Contractor	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Ag North	50	25	25	100	35	100	100	90	100	100	100	60	100	100
Ag South	50	25	25	50	35	100	95	90	100	70	65	49	70	75
M&I North	50-75	25-50	75	100	75	95	100	90	100	95	100	85	100	100
M&I South	50-75	25-50	75	75	75	100	100	90	100	95	90	77	95	100
Refuges North			75	100	75	100	100	100	100	100	100	100	100	100
Refuges South			75	75	75	100	100	100	100	100	100	100	100	100
Settlement & Exchange	100	75	75	100	75	100	100	100	100	100	100	100	100	100

Note:
[1]Percent of CVP contract quantities

POTENTIAL PARTICIPANTS FOR CONJUNCTIVE WATER MANAGEMENT PROGRAM

This sections discusses several requirements for participation and opportunities for participation based on contract type.

General Requirements for Participation

An in-lieu conjunctive water management component for SLWRI would require program participants with substantial existing natural recharge, and a groundwater basin capable of producing enough yield to carry participants through a brief dry period. For extended dry periods, additional surface water deliveries would be required. If natural recharge were insufficient during wet years, groundwater would not be recharged sufficiently and might not be available to exchange for surface water during dry years, reducing overall effectiveness of the conjunctive water management program.

A potential participant also would need to have access to surface water during wet periods. As mentioned, Delta exports are currently near their maximum during wet periods. Therefore, limited capacity exists to make increased (in-lieu) deliveries during wet periods. For this reason, south-of-Delta contractors cannot take advantage of a conjunctive water management program as effectively as north-of-Delta contractors.

In addition, a potential program participant would be subject to shortages and deficiencies in surface water deliveries. Contractors already receiving all of, or the majority of, their surface water demands in wet years would not benefit from increased deliveries. For this reason, Settlement and Exchange contractors are not ideal participants; they already receive their full demand for all years except the driest, and are not subject to the same reductions as Ag and M&I contractors. Ag and M&I contractors, however, often receive less than their full demand of surface water deliveries. A conjunctive water management program would use groundwater pumping to make up the remainder of Ag and M&I contractor demand during times of surface water shortage. As a result, Ag and M&I contractors are ideal candidates for a program that would increase their surface water deliveries in wet years and decrease deliveries in the driest years, thus providing groundwater storage for use during dry periods.

Opportunities Based on Contract Type

Opportunities for conjunctive water management differ between water contract types, which include settlement and exchange contractors, municipal and industrial contracts, and agricultural contracts.

Settlement and Exchange Contracts

Holders of Settlement and Exchange contracts would have limited ability to participate in an in-lieu conjunctive water management program associated with a Shasta Reservoir enlargement. Holders of both contract types normally receive all of their contract quantities in all years except years characterized by the Shasta Lake Water Year Classification Index as critical. As a result, any additional surface water deliveries for any other year types would be in excess to settlement and exchange contract quantities.

Municipal and Industrial Contracts

M&I contracts are subject to shortages, and deliveries during shortages are supplemented by groundwater. M&I contractors are more sensitive to shortages than other contract types, due to the nature of their demands. For example, fallowing land or changing an irrigation practice is appropriate for dealing with shortages in agriculture, but M&I water users are less flexible in adjusting their demands. As a result, shortages are typically covered through either groundwater pumping or purchasing/transferring water from another contractor.

To make use of a potential conjunctive water management program, an M&I contractor would need adequate conveyance capacity and increased treatment capacity for the additional surface water deliveries. Also, M&I water users are more sensitive to the quality of their water than agricultural users. Consequently, conveyance and treatment facilities may be needed for the groundwater component, since an increased portion of the user's demand would be met through groundwater deliveries during dry periods. In addition, natural groundwater recharge should be sufficient to recharge the basin at a rate to accommodate short historical droughts after several years of reduced groundwater extraction.

Agricultural Contracts

Ag contractors are believed ideally suited for a conjunctive water management program, particularly north-of-Delta Ag contractors. Of the three contract types, Ag contractors are subject to the greatest cuts in deliveries and, as a result, could most frequently use an additional increment of surface water. Further, north-of-Delta Ag contractors are not subject to Delta export limitations, and the Sacramento Valley has significantly higher natural groundwater recharge rates than the San Joaquin Valley. Ag contractors in the Sacramento Valley depend on groundwater to make up for shortages in contract surface water deliveries, and there is likely enough local demand to attract users for the program.

Impediments for north-of-Delta contractors include the CVP's tiered pricing program. This program, part of the Central Valley Project Improvement Act (CVPIA), charges progressively higher rates for water as the contractor's surface water deliveries approach their full contract entitlement. The higher prices are an incentive for the contractors to forgo their surface water allocation and use groundwater instead. When their full allocation is not taken, the water is available for environmental purposes or for export at the Delta. If additional surface water deliveries are more expensive than groundwater, no incentive exists for Ag contractors to participate in a conjunctive water management program. Consequently, revising the tiered pricing program to reflect year types and available surface water would be helpful for implementing an effective conjunctive water management program north of the Delta.

IMPLEMENTING A CONJUNCTIVE WATER MANAGEMENT PROGRAM

If a conjunctive water management program component were added to a plan to enlarge Shasta Dam and Reservoir, the program would likely include participants from north of the Delta. Both Ag contractors and M&I contractors would be likely participants.

North-of-Delta Agricultural Contractor

Facilitates and costs for north-of-Delta Ag contractors participating in a conjunctive water management program are described in this section.

Facilities

Implementing an in-lieu conjunctive water management program potentially would include development of additional groundwater resources to produce dry-period yield. For example, the simulations described in the following chapter show a peak increase in groundwater usage in June of 1988 of 7.7 thousand acre-feet (TAF). To pump an additional 7.7 TAF, new wells and conveyance facilities probably would be required. With cooperation between private well owners and water districts, coordinated operations and an aquifer-wide management plan could be developed to efficiently operate the conjunctive water management program by locating new well sites and coordinating existing well operations. Installation of new wells and coordinated operation of existing wells may require air quality studies due to the large number of diesel-powered groundwater pumps in this region.

Costs

With an estimated increase in monthly groundwater extraction capacity of 7.7 TAF required, as many as sixty 1,500-gallon-per-minute wells would be needed. With an estimate of $500,000 per well, including new conveyance capacity, the cost of a conjunctive water management program as described above would be around $12 million. Existing pumping capacity may be in place to implement the program, but existing diesel wells may need to be replaced with electric wells to reduce air quality impacts associated with occasional increases in pumping.

North-of-Delta Municipal and Industrial Contractors

Facilities and costs for north-of-Delta M&I contractors participating in a conjunctive water management program are described in this section.

Facilities

Existing studies are underway examining the potential for several water interests to take a portion of their CVP contracts from the Sacramento River rather than from other sources. In these instances, opportunities may exist to time increased normal and wet period releases from Shasta Dam to allow these contractors to use potential excess installed pumping/diversion capacity and take their supplies from the Sacramento River. Similar to the Ag contractors, M&I diversions from the Sacramento River could be sized for full delivery, which provides capacity for extra water from Shasta Reservoir when allocations have been reduced by the CVP.

Costs

With the infrastructure in place, potential costs for implementing a conjunctive use project would be minimal.

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CHAPTER III
SIMULATED CONJUNCTIVE WATER MANAGEMENT OPERATIONS

For initial evaluation purposes, a theoretical in-lieu conjunctive water management program was developed. The approach identified for this theoretical scenario is an example of a conjunctive water management program that could be developed in conjunction with other components (i.e., raising Shasta Dam) of the SLWRI.

APPROACH

Simulations of the CVP and State Water Project (SWP) are conducted using the CALSIM II statewide planning model (see **Appendix A**). The studies cited below used a 2020 level of development for demands, and were simulated using D-1485, D-1641, and the CVPIA (b)(2) restrictions within CALSIM II. Conjunctive water management studies for the SLWRI used the Tehama-Colusa Canal (TCC) contractors as an example participant for north-of-Delta Ag contractors.

A separate allocation scenario was developed for the TCC contractors using the CVP agricultural allocations as a decision variable. As previously described, contract status and delivery allocation for contractors is assigned through a priority system. TCC deliveries were assigned a fourth-level delivery status, meaning they received additional surface water deliveries in wet years, but reduced deliveries in dry years. After multiple iterations and simulations varying the quantity of water allocated to TCC contractors, an allocation scenario was identified that placed conjunctive water management participants at a priority below M&I, but above other Ag contractors. **Table III-1** shows TCC deliveries as they relate to M&I allocation and other Ag contract deliveries.

TABLE III-1
CVP CONTRACT ALLOCATION PERCENT COMPARISON

Ag Allocations (%)	M&I Allocations (%)	North-of-Delta Ag Conjunctive Use Participant Allocations (TCC Allocations) (%)
100	100	100
75	100	100
50	75	75
25	75	50
0	50	0

Key:
Ag – agricultural M&I – municipal and industrial TCC – Tehama-Colusa Canal

Under this scenario, TCC contractors received their full contract quantities while other Ag contractor deliveries were reduced to 75 percent of their contract quantities. As CVP deliveries were reduced below 25 percent, TCC deliveries were eliminated entirely, requiring that TCC contractors use groundwater during this time. **Figure III-1** shows the exceedence probability of

annual deliveries of north-of-Delta agricultural contracts for three simulations: without-project, 18.5-foot raise of Shasta Dam (WSR-2), and an 18.5-foot raise of Shasta Dam with conjunctive water management (WSR-4, CO-5).

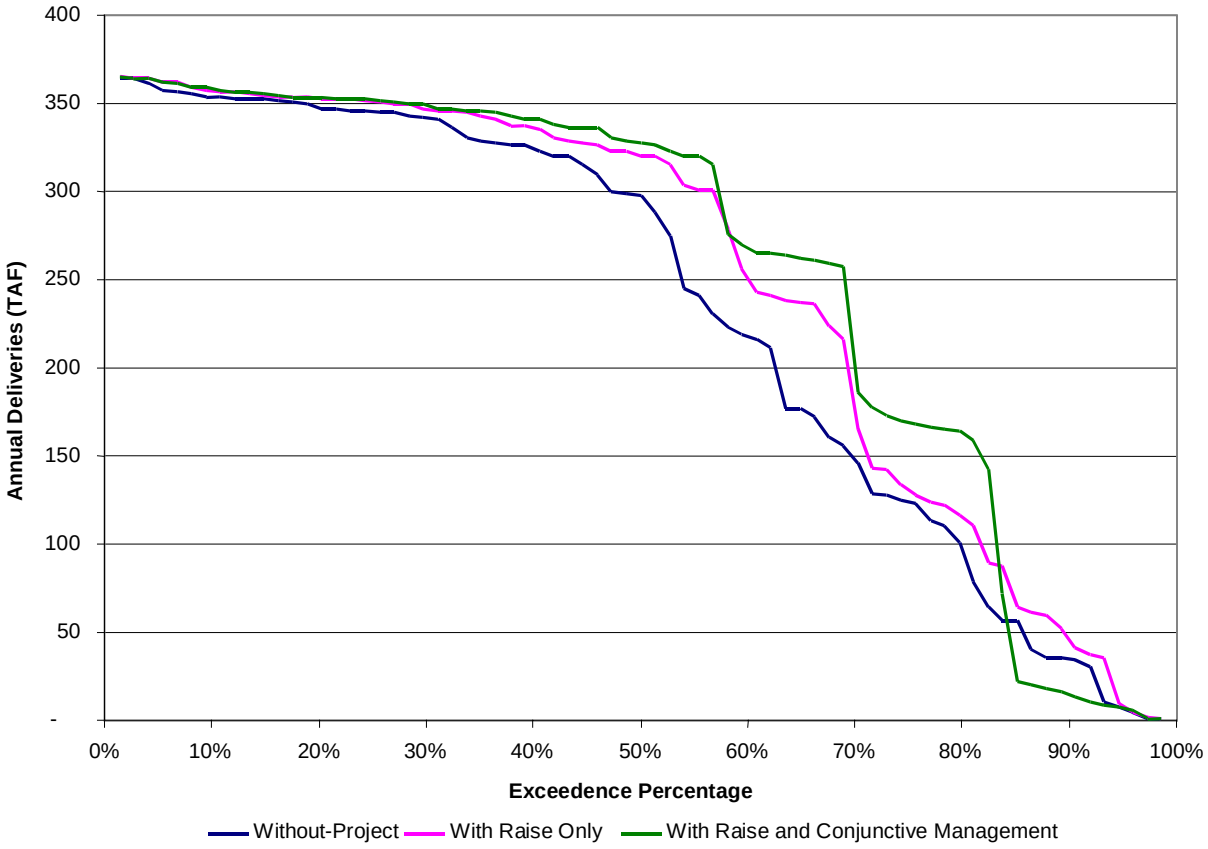

Figure III-1. Exceedence Percentage of Simulated Annual Delivery for CVP NOD Ag

Figure III-1 illustrates the increase in deliveries for most year types and a drop in deliveries during the driest periods for conjunctive water management program participants. This specific pattern of conjunctive water management is simulated in the WSR-4 and CO-5 concept plans.

RESULTS

Water supply reliability and salmon mortality modeling results are described in this section.

Water Supply Reliability

Several of the concept plans, including WSR-4, CO-4, and CO-5, incorporated a conjunctive water management component in their formulation. Simulations show that both enlargement of the dam and the conjunctive water management program increase deliveries in both average annual years and in dry and critical years to the CVP, as shown in **Table III-2.** Enlarging the dam by 18.5feet provides 138 TAF during dry and critically dry years. The 18.5-foot dam raise combined with a conjunctive water management program provides 162 TAF during dry periods. The additional 24 TAF above the raise-only simulation is attributable to the conjunctive water

management program. Although some efficiency is lost by combining the 18.5-foot dam raise and the conjunctive water management program, this combination (WS-4 and CO-5), provides the largest dry-period yield of any of the concept plans analyzed.

TABLE III-2
COMPARISON OF SIMULATED CVP DELIVERIES

Concept Simulated	Average Annual CVP Deliveries (TAF)	Dry and Critical Year Annual Deliveries (TAF)
Without-Project		
Delivery	5,025	4,416
Conjunctive Water Management with Existing Reservoir (not evaluated as a concept plan)		
Delivery	5,042	4,461
Increase over Without-Project	18	45
6.5-Foot Raise (WSR-1, CO-1)		
Delivery	5,075	4,498
Increase over Without-Project	50	83
6.5-Foot Raise and Conjunctive Water Management (CO-4)		
Delivery	5,082	4,523
Increase over Without-Project	57	107
18.5-Foot Raise (WSR-2, CO-2, CO-3)		
Delivery	5,104	4,554
Increase over Without-Project	79	138
18.5-Foot Raise and Conjunctive Water Management (WSR-4, CO-5)		
Delivery	5,114	4,577
Increase over Without-Project	89	162

Key:
CO – combined objective CUP – central valley project TAF – thousand acre-feet WSR – water supply reliability

These simulations also show that both enlargement of the dam and the conjunctive water management program increase deliveries in both average annual years and in dry and critical years to the north-of-Delta Ag contractors, as shown in **Table III-3.** Enlarging the dam by 18.5 feet provides 27 TAF to these contractors during dry and critically dry years. The 18.5-foot dam raise combined with a conjunctive water management program provides an additional 35 TAF during dry periods. The additional 8 TAF above the raise-only simulation is attributable to the conjunctive water management program. Although some efficiency is lost by combining the 18.5-foot dam raise and conjunctive water management program, this combination (WS-4 and CO-5), provides the largest dry-period yield of any of the concept plans analyzed.

TABLE III-3
ANNUAL DELIVERIES TO NORTH-OF-DELTA AGRICULTURAL CONTRACTORS (TAF)

Concept Simulated	Average Annual NOD Agricultural Deliveries	Dry and Critical Year Type NOD Agricultural Deliveries
Without-Project		
Delivery	233	113
Conjunctive Water Management with Existing Reservoir (not evaluated as a concept plan)		
Delivery	242	123
Increase Over Without-Project	9	10
6.5-Foot Raise (WSR-1, CO-1)		
Delivery	245	131
Increase over Without-Project	12	18
6.5-Foot Raise and Conjunctive Water Management (CO-4)		
Delivery	251	135
Increase over Without-Project	18	22
18.5-Foot Raise (WSR-2, CO-2, CO-3)		
Delivery	251	140
Increase over Without-Project	18	27
18.5-Foot Raise and Conjunctive Water Management (WSR-4, CO-5)		
Delivery	258	148
Increase over Without-Project	25	35

Key:
CO – combined objective NOD – north-of-Delta TAF – thousand acre-feet WSR – water supply reliability

Salmon Mortality

The salmon mortality model was run for the without-project and all of the concept plans above and for the conjunctive-use-only scenario. Critical input information was taken from the CALSIM and temperature models. This model is discussed in detail in Appendix D. Primary output of the mortality model is population increases for each of the four runs of salmon in the upper Sacramento River as a function of water year conditions. These conditions are defined as wet, above normal, below normal, dry, and critically dry conditions. As shown in **Table III-4,** all of the concept plans increased total salmon populations over the without-project condition. In contrast, the conjunctive water management program with the existing reservoir had negative impacts on three of the four salmon runs. Accordingly, the conjunctive-use-only program would not likely be implementable unless combined with an enlargement of Shasta Dam.

TABLE III-4
SALMON POPULATION OVER 50-YEAR PERIOD

Initial Plan	Population Over 50-Year Period[1]				
	Fall-Run	Late-Fall-Run	Winter-Run	Spring-Run	Total
Initial Returning Population[2]	49,000	10,000	2,800	800	62,600
Existing Dam with Conjunctive water management					
Incremental Population in 50 Years [3]	48,282	10,014	2,624	731	61,651
Increase over Without-Project[4]	-718	14	-176	-69	-949
Percent Increase	-1	0	-6	-9	-2
Average Annual Increase	-14	0	-4	-1	-19
6.5-ft Raise (WSR-1)					
Incremental Population in 50 Years [3]	68,522	10,199	2,595	1,575	82,891
Increase over Without-Project[4]	19,522	199	-205	775	20,291
Percent Increase	40	2	-7	97	32
Average Annual Increase	390	4	-4	16	406
18.5-ft Raise Only (WSR-2)					
Incremental Population in 50 Years [3]	101,526	10,427	2,912	3,085	117,949
Increase over Without-Project[4]	52,526	427	112	2,285	55,349
Percent Increase	107	4	4	286	88
Average Annual Increase	1,051	9	2	46	1,107
18.5-ft Raise with Conjunctive water management (WSR-4)					
Incremental Population in 50 Years [3]	97,939	10408	2825	2622	113795
Increase over Without-Project[4]	48,939	408	25	1,822	51,195
Percent Increase	100	4	1	228	82
Average Annual Increase	979	8	1	36	1,024

Notes:

[1]Population increases over baseline condition.

[2]Based on average annual returning population for years 1996 through 2001.

[3]Based on population increase for each return cycle over 50 years (17 occurrences).

[4]Net increase over conditions, including increases due to temperature control device.

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CHAPTER IV
FINDINGS

Major findings of the conjunctive water management assessment include the following:

- A conjunctive water management program associated with the SLWRI would involve extracting groundwater strategically to increase local supply or to enable reduced diversions of surface water at critical times, and allowing the groundwater aquifer to recharge, either through in-lieu operations (natural recharge due to reduced pumping) or active recharge, during wet periods.

- System simulation modeling (CALSIM II) indicates that concept plans that include a conjunctive water management program, in comparison to raise-only concept plans, would increase water supply reliability in the CVP in dry and critical years.

- Concept plans that include a conjunctive water management program (i.e. WSR-4, CO-4, CO-5) have reduced fisheries benefits in comparison to dam raise-only concept plans (i.e. WSR-1, WSR-2).

- The potential success of a conjunctive water management program depends on engaging participants willing to enter into agreement (or change current agreement) regarding timing of their surface water deliveries from CVP.

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